Intersatellite Calibration of Polar-orbiting Radiometers using the SNO/SCO Method

Changyong Cao[1], Fuzhong Weng[1], Mitch Goldberg[1], Xiangqian Wu[1], Hui Xu[2], and Pubu Ciren[3]
[1]NOAA/NESDIS/ORA, Camp Springs, MD, USA
Changyong.Cao@noaa.gov
[2]IMSG Inc., Kensington, MD, USA
[3]QSS Group, Inc., Lanham, MD, USA

***Abstract*— There is an increasing demand for intercalibrating the polar-orbiting radiometers on different satellites to achieve the consistency and traceability required for long-term climate studies with the 25+ years of NOAA satellite data. Also, the calibration of current operational radiometers needs to be linked to those of the next generation NPOESS (National Polar-orbiting Operational Environmental Satellite System) satellites. The Simultaneous Nadir Overpasses (SNOs) /Simultaneous Conical Overpass (SCO) method developed at NOAA/NESDIS has been applied to the intersatellite calibration of radiometers in the infrared, visible/near-infrared, and microwave with excellent results. In this paper, the SNO/SCO methodology is introduced. Preliminary intersatellite calibration results for AVHRR, MODIS, SSM/I, AIRS, HIRS, and AMSU on operational and historical satellites are presented. The plans for establishing the calibration links between POES (Polar Operational Environmental Satellites) and NPOESS radiometers using the SNO/SCO method are discussed.**

***Keywords*: Intersatellite calibration, radiometer, SNO, SCO, POES, NPOESS**

I. INTRODUCTION

Intercalibrating the polar-orbiting radiometers on different satellites is critical for achieving the calibration consistency and traceability required for long-term climate studies using the 25+ years of NOAA satellite data. Many inter-calibration studies have been performed in the past. But most of them are limited to match-up data sets acquired from different satellites with dissimilar instruments and that may have different observation times and viewing geometries, and in many cases rely on radiative transfer calculations to account for the observation differences. These restrictions introduce uncertainties in the intercomparisons.

In recent years, the Simultaneous Nadir Overpass (SNOs) method has been developed and refined for the intersatellite calibration of radiometers [1]. At each SNO, radiometers from both satellites view the same place within a few seconds at nadir, thus eliminating uncertainties associated with differences of atmospheric path, viewing geometry, and observation time. This is especially important for infrared radiometer observations, which vary significantly with these parameters. Subsequently, the Simultaneous Conical Overpass (SCO) method was developed for the conical microwave sensors.

The SNOs/SCOs for polar-orbiters occur in the polar regions (+/-70 to +/-80 degree latitude zone). The occurrence of the SNOs are due to the satellite altitude and orbital period differences between the two satellites. The larger the difference, the more frequent the SNOs. For example, SNOs between typical NOAA morning and afternoon satellites occur once every ~8 days, or about every 3 days between TERRA/AQUA and NOAA satellites. The mechanism of the SNO and its prediction are documented in [1]. Routine updates of the current SNOs for NOAA and TERRA/AQUA satellites are available online [2]. To support long-term time series analysis, historical SNOs between succeeding pairs of NOAA satellites from 1980 to 2003 are published in [3].

The SNO/SCO method, when used properly and combined with time series analysis, may have profound impact on the intersatellite calibration across the board for satellite radiometers in the visible/near-infrared, infrared, and microwave. Before this method was used, intersatellite calibration biases often could not be separated from the true differences in the geophysical variables due to differences in the diurnal temperature (infrared and microwave) or Sun angle and bidirectional reflectance distribution function (BRDF) (solar reflective). As a result of using the SNO/SCO method, uncertainties in the intersatellite calibration are greatly reduced. In the last few years, with the SNO/SCO method, significant improvements have been made in quantifying the intersatellite biases, monitoring instrument performance, constructing long-term time series for climate studies, inflight spectral calibration, and characterizing sensor artifacts. In this paper, preliminary intersatellite calibration results for AVHRR, MODIS, SSM/I, AIRS, HIRS, and AMSU on operational and historical satellites are introduced. The plans for establishing the calibration links between POES and NPOESS radiometers using the SNO/SCO method are discussed.

II. APPLICATIONS OF THE SNO/SCO METHOD FOR THE CALIBRATION/VALIDATION OF SATELLITE RADIOMETERS

A. Applications of the SNO/SCO method for Sounders

The first documented study using the SNO method started in late 2001 for the intersatellite calibration of the High

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Resolution Infrared Radiation Sounders (HIRS) on NOAA-15 and -16. Since then, significant improvements have been made in the understanding of the mechanism and prediction of the SNOs, and its potential for intersatellite calibration. With institutional support, we analyzed all the SNOs for HIRS on NOAA-15, -16, and -17 from 2001 to 2003, and generated time series of the biases. Details can be found in [4], and significant findings are summarized below.

The HIRS study reveals unambiguous intersatellite radiance differences, as well as calibration anomalies. The results show that in general, the intersatellite relative biases are less than 0.5 K for most HIRS channels. The large biases in different channels differ in both magnitude and sign, and are likely caused by the differences and measurement uncertainties in the HIRS spectral response functions. The seasonal bias variation in the stratosphere channels are found to be highly correlated with the lapse rate (Figure 1), approximated by the channel radiance differences. The SNO method works particularly well for channels sensing the stratosphere because of its relative spatial uniformity and stability, for which the intercalibration accuracy are mostly limited by the instrument noise. This method is simple, robust, and the results are highly repeatable and unambiguous. Intersatellite radiance calibration with this method is very useful for the on-orbit verification and monitoring of instrument performance, and is potentially useful for constructing long-term time series for climate studies.

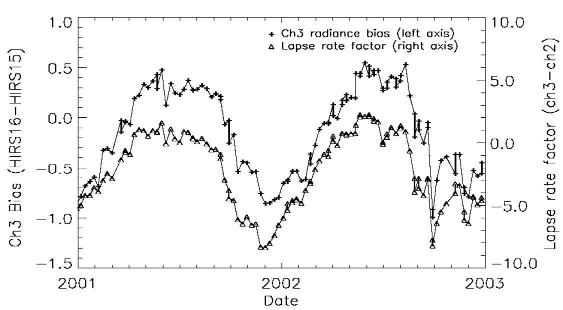

Figure 1. Correlation between the seasonal radiance bias (mW/(m^2·sr·cm^{-1})) for HIRS channel 3 (pluses with left Y axis) and the lapse rate, approximated by the HIRS 16 channel radiance difference (triangles with right Y axis)

The potential of inflight spectral calibration using the SNO approach was explored for AIRS and HIRS [5]. The broad band HIRS has spectral uncertainties due to the lack of stringent specification and onboard spectral calibration. Preliminary studies suggest that it is possible to spectrally calibrate HIRS using AIRS observations with the SNO method. The radiance bias between HIRS and AIRS changes as a function of spectral shift, and it is possible to find the spectral shift that produces the smallest radiance bias. However, radiance bias can be affected by many other variables. The relationship between spectral shift and radiance bias provides an important piece of information for solving the radiance bias equation [5], and can potentially be used for the inflight spectral calibration, once other major variables in the equation are quantified. A time series analysis of this relationship will further reduce the uncertainties in the spectral calibration.

The SNO method was further applied to the passive microwave sounding unit AMSU for the operational instruments on NOAA-16 and -17. Excellent agreement was found for the channels sensing the mid troposphere to the stratosphere between the AMSUs. For example, channel 5, which senses the mid-troposphere, has a intersatellite bias at ~0.1K with an uncertainty less than 0.2 K. Unfortunately, the AMSU-A on NOAA-17 failed in late 2003 which terminated the time series of the intersatellite calibration.

The SCO (Simultaneous Conical Overpass) method was later developed for the Microwave Conical Scanners such as DMSP/SSMI and applied to the SSM/I data. The conical scanners work differently compared to the nadir looking radiometers. Since the SSM/I takes forward/aft looking measurements, SSM/I sensors view the same location at approximately the same time but from different angles with a different path. Therefore caution must be exercised when interpreting the intersatellite biases. As an example, SCOs between F-10 and F-13 occur every ~5 days in the polar regions, and the intersatellite biases are typically on the order of a few degrees.

B. Applications of the SNO method for Infrared Imagers

The first SNO case study (not well documented) can be traced back to April 2001, when we investigated the intersatellite biases between NOAA-14 and -16 AVHRR for the longwave channels, in response to a user inquiry. Using Satellite Tool Kit (STK), we were able to visually identify one overpass between NOAA-14 and -16 which occurred within about 30 minutes (compared to a few second SNOs used today). We found that the channel brightness temperature difference for the same earth target was 0.4K at 250K. However, if the nonlinearity correction for NOAA-14 were not applied, the difference would be a few degrees, as the user claimed. Although we did not call this an SNO at the time, this is probably the first SNO study that was conducted.

A major milestone was reached in early 2002 for the intersatellite calibration between MODIS and AVHRR and the results for the infrared channels were first published in the SPIE proceedings [6], and a journal paper for the visible channels published later that year [7]. Since then, a collaboration with the NASA MODIS Characterization and Support Team (MCST) allowed us to perform intersatellite calibration using the SNO method for Terra and Aqua MODIS using the AVHRR as a transfer radiometer [8]. A consistent agreement between MODIS on Terra/Aqua is found for the 11um and 12um longwave channels since 2002.

C Applications of the SNO method for VIS/NIR imagers.

The usefulness of the SNO method for the visible/near-infrared channel calibration is demonstrated in the study using MODIS to calibrate AVHRR reflectance channels [7].

Traditionally, vicarious calibration using the desert target is performed routinely for the AVHRR visible/near-infrared channels since there is no onboard calibration for these channels. It is generally agreed that the vicarious calibration using the desert has an uncertainty about +/-5%, compared to the +/-2% uncertainty of MODIS with onboard calibration. Using the SNO method, the MODIS calibration can be effectively transferred to AVHRR with uncertainties probably smaller than +/-5%. Later the intersatellite biases between NOAA-16 and -17 are made available online and updated routinely (http://www.orbit.nesdis.noaa.gov/smcd/spb/calibration/sno/sno.html). The time series clearly shows that the intersatellite biases changed when major updates for the calibration coefficients were made.

III. ESTABLISHING THE CALIBRATION LINK BETWEEN POES AND NPOESS RADIOMETERS

The SNO/SCO method can be used for the intersatellite calibration between POES and NPOESS radiometers. The significance of this calibration link cannot be underestimated. First, this will be an important risk reduction for NPP/NPOESS instruments. It serves as a truly independent verification of the calibration between satellites, and it is a complement to all the other calibration/validation activities planned for NPOESS. The SNO/SCO method will allow us to examine the calibration biases between POES and NPOESS radiometers with little ambiguity. The dependency on radiative transfer models in the calibration/validation is greatly reduced, so are the uncertainties associated with it. The low cost, sustainability, and same view geometry and path are significant advantages over alternative calibration/validation methods.

Second, at NOAA, we are already using the SNO/SCO method for the retrospective intersatellite calibration of the 25+ years of satellite data to support climate trending studies [3], [8], [9]. Under the science stewardship program, we are using time series to characterize the intersatellite biases between succeeding satellites from NOAA-6 to NOAA-17 (from 1981 to 2003) for the HIRS, AVHRR, and MSU. The method will then be used for validating the calibration improvement after new calibration algorithms are implemented to resolve the biases. The intersatellite calibration between POES and NPOESS will be a natural extension of this effort to ensure the continuity, and consistency of the operational environmental satellites to support climate studies.

Third, there is a strong need for inflight calibration traceability. Currently the NIST (National Institute of Standards and Technology) traceability of satellite radiometers is based on prelaunch laboratory calibration and is inadequate for inflight calibration applications because the operating conditions of the radiometers have changed and will change over time at different time scales. The intersatellite calibration between POES and NPOESS will be a significant step forward in that direction. Eventually, intersatellite calibration using this method for a constellation of all satellite radiometers will allow us to establish an integrated system for the global radiance calibration traceability, which is consistent with the GEOSS (Global Earth Observation System of Systems) initiative.

In preparation for the intersatellite calibration between POES and NPOESS using the SNO/SCO method, we have started experimenting using NOAA and TERRA/AQUA satellite data as substitutes, e.g., intersatellite calibration between AVHRR and MODIS, between HIRS and AIRS, and between SSMI on different DMSP satellites. With support from the Integrated Program Office, we plan to expand the capabilities to include intersatellite calibration of NPP/NPOESS sensors using the SNO/SCO method. A software tool and system will be developed for the long-term independent monitoring of instrument performance, improving calibration consistency across satellites, and establishing on-orbit calibration traceability for the NPP/NPOESS satellites. The system will be used for the calibration/validation and long-term monitoring of VIIRS, CrIS, ATMS, and CMIS, with calibration links to MODIS, AVHRR, HIRS, AMSU, and SSMI. Calibration biases and statistics for all instruments will be made available on the web with routine updates. The current website (http://www.orbit.nesdis.noaa.gov/smcd/spb/calibration/sno/sno.html) will be expanded to include NPP/NPOESS intersatellite calibration in the near future. Assuming that NPP/NPOESS satellites will have an orbital period of ~101 min which is similar to that of the current POES satellites, it will have SNOs with TERRA and AQUA every few days, providing excellent opportunities for the intersatellite calibration. The frequent SNOs between TERRA/AQUA and POES/NPP/NPOESS satellites is a distinct advantage for intersatellite calibration with the SNO/SCO method. In addition, the TERRA/AQUA data are excellent substitutes for NPP/NPOESS for intersatellite calibration, before those data become available.

IV. CONCLUSIONS

There is an increasing demand for more accurate radiances for numerical weather predictions. Also, climate trending critically depends on long-term accurate and reliable calibration across satellites. The SNO/SCO method developed by NOAA/NESDIS scientists is a potentially enabling technology for meeting such challenges. It provides unique opportunities for a variety of applications including the intersatellite calibration of radiometers in the infrared, visible/near infrared, and microwave, and so far it has produced excellent results. At each SNO, the radiometers on two satellites view the Earth and its atmosphere at nadir within a few seconds, providing an ideal scenario for the intersatellite calibration. While the SNO is used for most imagers and sounders, the SCO method is applicable to conical microwave scanners. In this paper, applications of this method for monitoring the on-orbit performance of satellite radiometers, and for improving the consistency and traceability required for long-term climate studies with the more than 25+ years of NOAA satellite data are introduced. The plan for establishing the calibration links between the current POES and the NPOESS satellites is also presented.

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